Unmanned Aerial Vehicles (UAVs) as on-demand QoS enabler for Multimedia Applications in Smart Cities

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Unmanned Aerial Vehicles (UAVs) as on-demand QoS enabler for Multimedia Applications in Smart Cities

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***Abstract*—The evolution of drones and similar small wingspan UAVs has resulted in their use in many commercial applications. This has allowed investigating the potential use of drones in the context of Internet of Things. In the recent past, there is ample evidence indicating the use of UAVs as a means to supplement mobile infrastructure to extend it for surveillance, monitoring, data collection and providing on-demand network access capabilities. This paper explores the potential of UAVs to act as on-demand QoS enablers for TCP-based applications within Smart Cities, particularly those applications that require low connection delays, reliability and high throughputs such as multimedia streaming.**

Many multimedia rich applications, such as live streaming, multi-player online gaming are mostly tied down to fixed-line broadband infrastructure. Mobile cloud technologies and Mobile Edge Computing (MEC) address the challenge by bringing the computing, storage and networking resources to the edge and integrating with the base station, thereby providing better content delivery. The paper presents a concept of UAV-based aerial MEC, which hosts a TCP-proxy that acts as an 'On-Demand QoS' enabler to TCP-based applications in Smart Cities reducing the overall-connection delays and increasing the throughput thereby enhancing the end-user experience. With the technologies available in literature we demonstrate that a UAV-based aerial MEC with the capability to migrate QoS-enabling processes from the edge to the core and edge to the edge, to support mobile applications, is feasible.

***Index Terms*—QoS, QoE, process mobility, proxy, proxy-caching, split-TCP, UAV, Drones, mobile edge computing, MEC, component, formatting, style, styling, insert**

I. INTRODUCTION

Smart cities comprise of large and robust communication infrastructure fabric offering evolving and innovative services. The infrastructure is a combination of several digital information and communication technologies, which are scaled to meet the requirements of the city. The basis of smart cities is the digital infrastructure that provides users' access to the information services, stakeholders' data, analytics and intelligence, as well as a safe and reliable channel to implement a dynamic control for various services. The Internet of Things (IoT), which has now proliferated across all service sectors and is used for routine monitoring and controls, is based on a network of interconnected sensors and actuators. Such sensor networks form the end points of a smart city infrastructure and are predominantly used for monitoring data.

Some monitoring scenarios require mobility, such as monitoring vehicle movement (freight movement, traffic monitoring, etc.), crowd monitoring and so on. The sensors, in these scenarios, can be on the subject being monitored or on a mobile entity that monitors a large area. It is in the latter context that unmanned aerial vehicles (UAVs) have found tremendous use. UAV is a term used to denote an unmanned flying object that is capable of aerial self-stabilization and is not a kite, balloon or satellite. The term 'unmanned aircraft system' (UAS) is broader, and includes any wireless communication and detached hardware used to control the flight path. 'Remotely piloted aircraft systems' (RPAS) refers to the subset of UASs that are incapable of fully autonomous flight missions, and may also include remotely controlled aircraft that are not self-stabilizing [1]. The various types of consumer UAVs currently available off-the-shelf, the issues involved with UAVs when used for cellular communications as well as the associated security aspects are mentioned in [2].

UAVs have been in use for over a decade, largely in military applications. [3] provide a detail of several civil UAV applications until 2004, especially for science and research activities. They also list several civil application scenarios for assessing the capabilities of UAVs for civil use. Recently, the availability of "quadcopters", which are four-rotor helicopters without a tail rotor, is a commodity item available in supermarkets. They qualify as UAVs since they are unmanned, aerial and can be remotely controlled by radio. However, the flight times and payload capacity of the quadcopters are low compared to that of other UAVs. In the recent past, the term Unmanned Aerial Systems (UAS) is in use to denote a UAV and its ancillary systems on-board. The terms UAV, UAS and drone are used synonymously in our context.

This paper examines the potential applications of a UAV in a smart city scenario involving delay-sensitive and throughput-demanding applications such as multimedia streaming. The aim is to explore how UAVs could act as mobile infrastructure extender to these applications as well as enable on-demand Quality of Service and enhance the end-user experience. In this context, we further narrow our investigation to the potential deployment of mobile edge computing (fog computing) on UAV to act as a flying, on-demand QoS enabler to the needs of multimedia services. There have been proposals of using UAVs in the context of Ultra Dense Networks (UDNs) [4]. However, there are significant challenges in network-connected UAV communications, including UAV-to-UAV communications [5]. [6] illustrates the complexity in minimising the energy usage of a mobile user when providing cloud services on a fly-in MEC node on a UAV.

The paper is organised as follows. Section 2 mentions the performance need of typical Smart Cities applications and identifies the gaps which arise in the context of high-performance for mobile applications. Section 3 briefly illustrates how mobile-edge computing can potentially address the requirements for high performance. Section 4 presents MEC as a potential solution for the scenarios in section 2. Section 5 presents the existing work on addressing throughputs and delays with various UAV configurations and technologies, on-board. Section 6 examines the feasibility of hosting a TCP-proxy on an MEC infrastructure, on-board a UAV to act as a fly-in, on-demand infrastructure extender as well as QoS enabler for multimedia streaming applications and the paper concludes with our observations and future work in section 7.

II. Smart Cities Application Requirements

Literature review suggests while UAVs have found potential applicability within smart cities, they are largely limited to sensing, goods delivery and surveillance. Except for surveillance none of the above applications are network-intensive or performance-demanding applications (connection delays, throughputs and user experience). We aim to explore the potential use of UAVs in high-performance demanding applications. In the context of our discussion, we consider smart city applications that are mobile-platform centric and have high performance demands such as low connection delays and high throughput. Three typical applications, from a performance perspective, are listed below. Most other application scenarios can be treated as extensions of these.

1) Augmented Reality
   AR applications on a smart-phone or tablet overlays augmented reality content onto objects viewed on the device camera. AR applications find specific use in tourism and leisure industry, which include different categories of applications such as, parks and gardens, monuments, Points of Interest (POI), offices, art galleries, museums, libraries, culture events agenda.
   Other potential application areas are in maps, smart transport within public buses, taxis, parking places, etc., [7], [8]. With the ability to locate and communicate with mobile devices, there is an opportunity to deliver higher value to the consumers by implementing augmenting reality, improving the overall shopping experience. Large-scale deployment of AR applications faces certain challenges, mainly the need for accurate location tracking and efficient delivery of AR content, which is mostly high definition multimedia content to end-user mobile devices, which in most cases would be connected through inconsistent mobile access technologies such as 3G, 4G or LTE.
2) Secure Mobile Payments
   Successful deployment of mobile payments within smart city applications requires instant transaction response times and high reliability and no packet-loss [9], [10].
3) Video-streaming
   Video streaming applications form an integral part of many innovative smart city applications such as streaming multimedia content generated by journalists live recording and relaying news from a remote location, video streams recorded by spectators from live event and sporting venues where visibility to the center of action is limited. These video streams are typically transferred directly via the LTE network to the user equipment, enabling users to watch the stream in real-time [11]. Video streaming has additional areas of application such as emergency or disaster coverage, on-demand video surveillance of remote locations as well as multi-player online gaming, which is currently limited to fixed infrastructure and is not viable on mobile infrastructure due to poor response times, user-experience and network bandwidth availability. It is in this context, the paper proposes the use of UAV's to act as on-demand infrastructure extenders that hosts TCP-Proxy to reduce the connection delays and enhance the throughputs of live video streams generated by a journalist from a remote location or a live recording of a foot-ball match (any live event) by the spectators or live streams generated through video-surveillance of disaster-stricken areas.

In this context the emerging concepts of 'Mobile Edge Computing' address some of the challenges of Smart Cities multimedia applications.

III. MEC - Enabling Demanding Services

Currently, all computing and storage resources are centralised and located at the core of the network. Consequently, the delivery of content to the mobile end user is always from the core of the network. There is no application level intelligence on the network components from the core to the access. MEC provides a means of introducing the resources to build such intelligence, one specific component being location. Mobile Edge Computing (MEC) is simply computing resources at the edge of the mobile network. Typically, the edge of the mobile network has stacked resources necessary for network access and access related components. MEC proposes co-locating computing and storage resources at base stations of cellular networks. It is primarily expected to reduce the application latency for the mobile end users that use the network [12]. Mobile-edge Computing transforms base stations into intelligent service hubs that are capable of delivering highly personalized services directly from the very edge of the network while providing the best possible performance in mobile networks [13]. This is possible due to the all-IP characteristic of 4G, 5G networks that use LTE.

Nokia-Siemens illustrated the feasibility of MEC by demonstrating a platform designed to run applications within a base station of the mobile network (Nokia 2013). Subsequently, in 2014, the ETSI launched the Industry Specification Group (ISG) for MEC [13]. The objective was to provide an IT service environment and cloud-computing capabilities at the edge of the mobile network. The specification also pursues the creation of an open ecosystem, where service providers can deploy their applications across multi-vendor MEC platforms. Telecommunication companies would be responsible to deploy the MEC service environment in their infrastructure. In terms of the forthcoming 5G technologies, MEC can supplement the high bandwidth availability by localizing the services. [14] present a compelling case by presenting a potential applications architecture for the combined use of the technologies

Locating the computing and storage resources at the edge of the network provides significant benefits. From a network perspective, it provides control and buffering resources at the interconnection point of two different media (wireless - radio and wired - back haul). This is valuable for TCP-based services since localizing the TCP control across the radio network will enable TCP adaptation only across that segment (Fig. 3). Consequently, the number of concurrent connections across the back haul network can be reduced when a sufficient number of data buffers are provided at the edge. The performance of a split connection TCP proxy deployed in LTE's SAE-GW show significant performance improvement of file downloading,

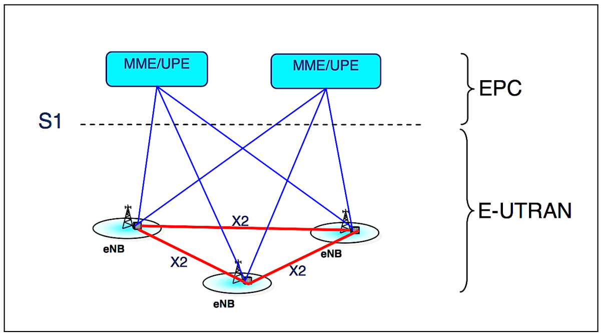

Fig. 1. The wired segment of the LTE network. User to eNB is wireless

web browsing and video streaming applications in case of non-congested transport networks [15]. [16] report a similar performance improvement in user throughputs when TCP sessions are split at local data centers closer to the user when the content is delivered from a remote data center.

From an applications perspective, applications (that do not use TCP) resort to buffering or caching data at the applications layer benefit from MEC. Multimedia applications, typically require intermediate buffering mechanisms to adapt to the delivery conditions. Such adaptation can effectively be done at the edge using the feedback of the network performance. [17] illustrates the impact of re-buffering on the quality of experience (QoE) in streaming applications, reflected as the mean opinion scores (MOS) of the end users. Such re-buffering can be avoided using MEC resources. Localized delivery of data from the MEC resource buffers can prevent starving of the play out buffers of the application on the end user's device.

Until recently, multimedia streaming from the core to the edge was predominant. With the availability of sufficient bandwidth and stable mobility and handoff mechanisms, multimedia streaming from the edge to the core as well as from the edge to the edge is emerging. Typical applications are in the case of journalism (on-site reporting), ambulatory use (real time monitoring and emergency care of a patient being driven to the hospital, by a remote doctor), video chats, and ad hoc user video streams from live events. [18] provide a typical illustration of an ambulatory use where they deploy multiple simultaneous paths to deliver real-time video from a mobile ambulance to a hospital. For ad hoc user streaming, the MEC elements can potentially provide stream end points for the user streams, where necessary. These end points can be published on the network as live streams available for subscription.

[19] classify the types of video delivery on mobile broadband networks (4G) into four classes, namely, Video-on-demand (VoD), Video multicast, Video chat and Video uploads. They mention that the type of application and network conditions largely affects the choice and performance of video service. Resilience to packet loss and power-efficient transmissions are important for all traffic classes. The QoS is a challenge for delivery of multimedia services, especially real-time interactive ones such as video chats. The acceptable end-to-end delay (encoding and decoding delay and transmission delay included) is bounded at around 150 ms. The bandwidth requirement could be 200 to 1,000 kbps, depending on the video characteristics and quality. [18] report the total bandwidth requirement for a 320x240 at 15fps is 1 Mbps. UDP is the chosen transport protocol for such applications, along with codecs with a low computing requirement. The significant difference in the multimedia traffic is that the point of origin has moved from the core to the edge. In summary, MEC adds computing and storage resources on to the network, but are located at the edge, as part of the radio access network (RAN). The location is an advantage from a network and an applications perspective. In the context of the smart city applications and the use of UAVs to supplement infrastructure or for Infrastructure-on-demand, MEC resources are additional components that require being located on the UAV.

IV. UAV-based MEC as a QoS Enabler

In this section, we start by mentioning UAV-based communications attempts and go on to discuss how these attempts could potentially provide a platform for a QoS service enabler. M/s Nokia, in the UAE, has done the first field demonstration of using UAVs with MEC. They have demonstrated a UAV Traffic Management utility that ensures safe UAV traffic management (UTM). It provides centralized monitoring and control of UAVs via an operator's existing LTE network equipped with MEC. Drones are equipped with LTE dongles, GPS and access modules for telemetry data. There are computing and processing components to monitor airspace, view and control drone flight paths and transfer telemetry data as well as establish dynamic no-flight zones. A mobile app is used for UAV pilot with the UTM interface [20]. With this precedent established, the combination of UAVs and MEC are here to stay.

In our context, we identify the use of UAVs as an infrastructure extension of the communication networks. The networks could be cellular broadband networks or Wi-Fi networks. The two primary uses are to provide radio coverage and to provide a relay between two ground stations using multiple UAVs [21]. Interference management across multiple UAVs providing coverage is a complex task, since the backhaul link is also a radio link.

There are two candidate technologies for the infrastructure extension, namely, wireless LAN and wireless broadband as in 4/5G. Drones can be used as a Wi-Fi access point (AP) due to the limited payload because the hardware for Wi-Fi is generally much lighter than that for LTE. Wi-Fi is limited by a narrow communication coverage compared to a cellular network as well as a relatively long handover time. Drones can be used as LTE nodes as part of the RAN. However, the weight of the equipment and the power requirements require a bigger and higher capacity drone. [22] consider the wireless communication between UAVs and to base stations as the primary building block of a larger network. They provide experimental results with 802.11ac and 802.11n with UAVs sending data to a ground station. They conclude that high throughput can be achieved with 802.11n using both infrastructure and mesh modes. The high mobility of the UAVs affects the transmit rates, and hence, the throughput and jitter. The variation in jitter will be of concern in case of multimedia traffic.

[23] experimented with UAV-to-UAV communication for purposes of bulk data transfers (pictures) using 802.11n. The 802.11n throughput drops far below the theoretical maximum and reaches throughput levels of 802.11a/g, despite its features such as transmit spatial coding, channel bonding, and frame aggregation. [24] used directional antennas and report throughputs of about 7 Mbps when the two UAVs were hovering

one kilometre apart. The throughputs increased as the UAVs hovered closer and reached an average of 36.2 Mbps at 150 metres.

[25] illustrate the use of aerial relays (UAVs equipped with eNodeBs) in (4G) cell overload and outage compensation scenarios. Using a swarm of six relays, they demonstrate a coverage extension of about 1000 meters at (40 dBm), in a cell outage scenario. Using four such relays provides an overall increase of 40 Mbps in the total system capacity. Guo et al (2014) have experimented with small UAVs on a 3G network in urban and rural areas at low altitudes (roof-tops) and illustrate consistent download throughputs for users covered by the Relay Node (RN) mounted on the small UAV.

[26] present a scenario where a swarm of UAVs can play a significant role as a communication network facilitator for users in specific areas with heavy traffic congestion, lack of communication infrastructure due to a disaster or at a remote location. They consider a UAV-based network to construct a multi-hop communication system. They point out that the trajectories of the UAVs have a notable impact on the communication delay and propose an algorithm to dynamically adjust the trajectories to improve the communications performance.

[27] propose multi-tier drone cells and a drone management framework using software defined networking (SDN), network functions virtualization (NFV), and cloud-computing. The drone cells bring the supply to where the demand is. [28] demonstrated an Aerial Base Station (AeNB) able to operate at 150 m altitude with 5 hours of autonomy, as part of an LTE network. The AeNB was mounted on a helikite and the equipment on-board was connected to the ground station via a 500-meter fiber optic cable that ran along the tether line of the helikite.

Although there are a number of studies so far in terms of measuring data throughputs, they have largely been on Wi-Fi. There have been no studies done on multimedia data transfers and related throughputs or data throughputs on LTE aerial base stations. [22] confirm this with the lack of references to QoS studies in literature, in this context, in their survey. They point out that the supportable network QoS is dependent upon the links (air-to-air, air-to-ground, ground-to-air). Each of these link types has different link characteristics, which limit the traffic sustainable on them. The terrain causes a wide variation in traffic capacities. Mobility, if present, adds to this variation.

In summary, the studies so far have demonstrated the feasibility of extending the coverage by using UAVs. Predominantly, the studies have involved Wi-Fi extensions with a few studies on LTE extensions. There are issues to be resolved in such infrastructure extensions - modeling the links to/from/between the UAVs, handoffs across UAVs in a multi-UAV coverage scenario and the ability to provide throughput and similar QoS guarantees to end users in an infrastructure extended coverage. Note that in terms of extended coverage, UAVs are well suited to provide LTE relay functions. Our focus is on the potential of UAVs providing aerial LTE base stations (eNodeB).

V. Air-borne MEC

We now explore the potential of MEC in such infrastructure extension scenarios. [13] lists various use cases where MEC would enhance user services in different ways, namely, speeding up application loading/access, location awareness to applications, location tracking, RAN-aware content optimization for delivery, and video analytics which are aimed at improving throughputs and the overall QoS for the user. [11] adds on to this list Augmented Reality, Intelligent Video Acceleration, Connected Cars, and Internet of Things Gateway. The MEC infrastructure is collocated with the LTE macro base station (eNodeB) site, at the 3G Radio Network Controller (RNC) site, at a multi-Radio Access Technology (RAT) cell aggregation site, and at an aggregation point (which may also be at the edge of the core network) [11]. The MEC resource at the edge could potentially be a cloud, given the number of services it could potentially host.

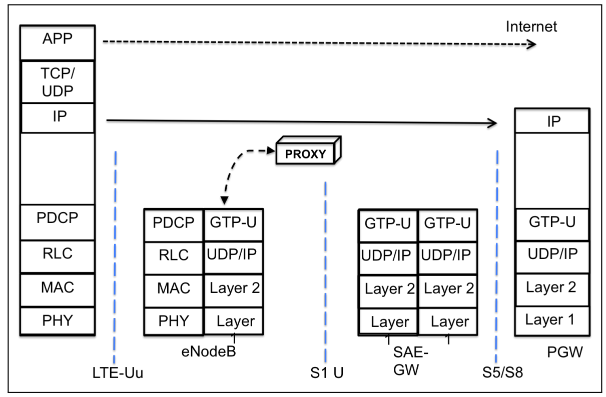

Fig. 2. Splitting TCP connections - migrate from Scenario 1 to 2. 3 is an ideal case.

In terms of QoS enablement, our specific focus is on TCP oriented services. The effect of varying packet delivery ratios across the radio network is well known (Fig 4). The varying characteristics of the radio network cause long-lived TCP connections due to reduction of the TCP window and its slow increase, resulting in a large number of concurrent TCP connections. These connections load the intermediate systems and the wired segment of the provider network is largely underutilized. [29] presents a detailed experimental analysis of split-TCP/TCP proxy connections, which includes secure socket connections. In a LTE network, user mobility is an important factor. This determines the location of any intrusive means of regulating TCP throughputs; the location must not impede mobility in any manner.

[15] use a TCP-proxy for a split TCP service and locate it at the SAE-GW and at the eNodeB in the LTE network. The SAE-GW handles mobility for the user plane traffic. The TCP proxy at the SAE-GW results in lower TCP connection set up times and data transfer times. However, the network segment is a combination of a radio segment and a wired segment and therefore the radio segment variations dominate the TCP performance on the UE to SAE-GW segment. The experiments show a considerable improvement in TCP throughputs with a high fairness index when the network is not congested. When congested, there is no significant improvement in the throughput and there is an impact on the fairness for users.

We explore the potential of locating the TCP proxy at the eNodeB. We extend our discussion based on the following ideas:

1) That it is possible to include a computing element, intrusively, in the network path between the eNodeB and the S1 and the Radio bearer (Fig 5, 6)

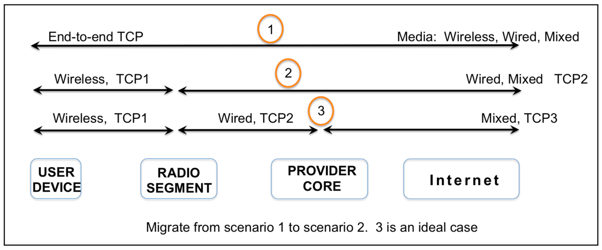

Fig. 3. Locating the proxy between the radio bearer and S1

2) That the computing elements across a telecom provider's data centre and the MEC resources form a cloud
3) That the processes or virtual machines can migrate across the provider cloud

The TCP proxy requires to be located in the path of the traffic to be able to transparently proxy the requests at the proxy. Therefore, it is located in the network path without altering any basic function of the LTE network. The proxy will examine all traffic originating from the UE. TCP traffic will be proxied and other traffic will be passed through. In the event of failure of the proxy, the traffic will still pass through the interfaces of the proxy, passively so that the service to the user is not hindered. The TCP proxy, in addition to the proxying, can host additional application service components, if necessary. It is already stationed at the edge of the network.

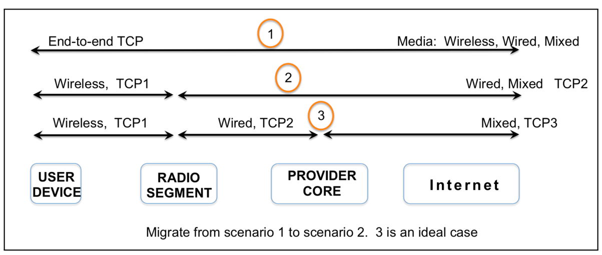

Fig. 4. LTE User Plane Protocol Stack

The computing elements across the provider network, which includes those at the core (data centres) and at the edge (MEC resources, including the TCP proxy), can be part of a single cloud infrastructure. It could encompass various computing resources with varied configurations and different resource (CPU, on-board memory, storage, network interface, etc.) capacities. This can facilitate migration of processes or virtual machine (VM) instances across the cloud. Such a migration would facilitate a smoother and faster handover when the user is mobile. A user owned process at one eNodeB could be migrated to another eNodeB where the mobile user has been handed off. Recall that the mobility and handoffs are managed at the SAE-GW, which is located in the core. The cloud is expected to facilitate the migration of the associated processes (including an active TCP session) to a corresponding computing resource at a eNodeB. When the active TCP session is migrated, the session is migrated with its current TCP parameters (congestion window size, timers, RTTs) and resources (buffers and its contents). The user facing TCP connection requires realigning itself to the new radio access conditions prevailing post handover.

[30] term the cloud that extends across a variety of computing elements as a superfluid cloud. Deployment of commodity hardware at the edge and the availability of low- cost, low-energy microservers (CubieTrucks, Raspberry Pis, fit-PCs, etc.), which can be used to push the cloud to the edge of the network by deploying them. They term this infrastructure of computing devices and the network as the superfluid cloud - a model where multi-tenant, virtualized software-based services run on common, shared commodity hardware infrastructure deployed throughout the network. Service instantiation could be done on-the-fly and on-demand as well as migrate them almost instantaneously (in a few milliseconds). The process migration times between servers with 2.x GHz CPUs was between 400 and 515 milliseconds. Note that this is already a factor of ten more than the handover delays in the C-plane and U-plane of LTE [31]. [30] mention two use-cases, which are of interest in our context – Virtual content data networks (VCDN) and on-the-fly services (OTFS). While VCDNs are clearly for content caching and delivery, OTFS provides the user a means of dynamically enabling services features and the provider a means of enabling/disabling network facilities. The idea of OTFS is based on JITSU [32]. One of these service features can be the transparent split TCP service (proxy). The provider can trigger on-the-fly TCP proxy when there is a TCP connect request from the user. [33] present a similar implementation of a mini-proxy. It is packaged as a single VM, with a footprint of 6 MB and a boot up time of 30 milliseconds for a 800 MHz CPU and increases to about 230 ms when the RAM increases from 6MB to 512 MB.

Our context is an inclusion of these technology implementations to provide a MEC enabled aerial eNodeB. The UAV will house an eNodeB as well as a MEC element on-board. The physical configuration of the MEC resource is limited by the availability of power. Given the limited power scenario, the role of the MEC resource is limited to proxying. The MEC resource is part of the extended cloud [30] in the provider's network and uses the miniproxy implementation [33].

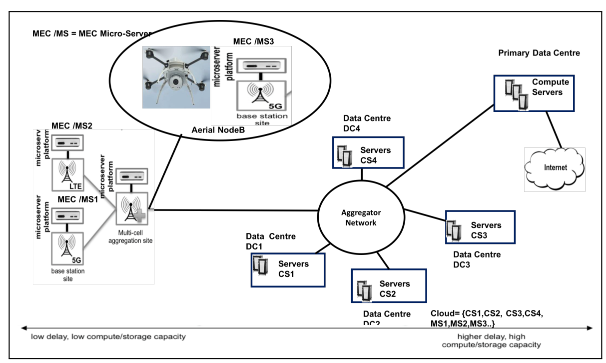

Fig. 5. LTE User Plane Protocol Stack

VI. Ongoing Work

Having established the feasibility of a potential on-board system for a UAV that not only provides extended coverage but also acts as a proxying service to enable a basic QoS enhancing feature, our current attempts are focused on:

1) Evaluating various hardware options for on-board use, their power requirements and peripherals
2) Estimating the working memory requirements for a TCP proxy – memory requirements for a TCP connection, Sizing TCP read and write buffers based on the radio

segment characteristics and the maximum number of connections for a given working memory
3) Simulations of data transfers across 4G and 5G RANs
4) Providing triggers for process/VM migration to the provider cloud, and
5) Estimating the duration of data stalls at the user end, following a handover
6) Evaluate other potential QoS enhancements, specifically network related, in the context of virtualized core with SDN and NFV [34]

VII. Conclusion

UAVs are invaluable means of providing services both in disaster situations and infrastructure extensions to service congestion scenarios or location of special events such as Fairs, Concerts, Markets and even demonstrations. UAVs with cameras on-board are used widely for visual coverage in these scenarios. MEC is a recent addition to data networks that brings computing to the edge and opens up a wide range of possibilities. In this paper, we explored the possibility of using MEC on-board a UAV to provide QoS enhancement to TCP-based applications.

In general, the communication networks supporting these applications are characterized by a wide variability in packet loss, delay, and throughput. Furthermore, a variety of receiving devices with different resources and capabilities are commonly connected to a network. In this context, coding and transmission technology, able to engineer the content to meet demanding application requirements, is critical. As a consequence, methods and models for scalable media compression, transmission and error concealment, play key roles. While this paper has outlined the use of on-board MEC on a UAV that hosts a TCP-proxy providing enhanced QoS in terms of connection delay and throughputs to TCP-based applications. We have highlighted some challenges in terms of power-requirements, memory and other implementation hurdles, however they are, by no means complete. New issues will be uncovered as the TCP-proxy is implemented and tested in time to come.

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